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AN ESTIMATION OF PARAMETERS FOR HOMOGENOUS UNCONFINED AQUIFERS USING DELAYED YIELD TYPE CURVES

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ABSTRACT

In order to know the groundwater potential in an area and to see the effect of pumping on groundwater system, it is important to know the aquifer parameters. Similarly, problems related to groundwater like scarcity of groundwater due to excessive pumping, contamination of groundwater etc., require a fairly accurate knowledge of these parameters. The present study aims at finding out the aquifer parameters, i. e., specific storage and transmissivity, for homogeneous and layered unconfined aquifer by using delayed yield type curves. Pumping tests were carried out in laboratory on groundwater abstraction apparatus to obtain the time drawdown curve, which were then utilized to calculate values of specific storage and transmissivity. Effect of the position of the observation well, with respect to the pumping well, on the consistency of result was analyzed. It was found that the observation well closer to the pumping well provided more consistent results compared to that which was farther, possibly due to boundary effects.

***KEYWORDS:** Aquifer Parameters, Pumping Well, Specific Storage & Transmissivity*

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Original Article

INTRODUCTION

Aquifer

An aquifer is the geological formation which can store as well as transmit water to the wells, springs and some streams. The pores of the soil are connected and thus allow water to move from one space to another. Wells can be drilled into aquifers and water can be pumped out. Precipitation and the flowing rivers add water to the porous rock of the aquifer, called recharge of the aquifer. Pumping too much water at a faster rate may make a well yield less water or run dry.

Aquifer Parameters

The aquifer parameters such as hydraulic conductivity, transmissivity and storage coefficient are important parameters which represent the potential of an aquifer for water development.

The hydraulic conductivity is a parameter of the soil, which is generally represented by K and which describes the ease with which water can move through the soil pore spaces. It is mainly dependent on the grain size, pore size and the texture of the soil. The experimental approach by which K is estimated is based on the Darcy's law which is given by $v=Ki$, where v = flow velocity and i is the hydraulic gradient (h/L), with h being the head difference over a distance L. The SI unit of K is m/s, but it is typically expressed in cm/s or m/d.

Transmissivity can be defined as the rate at which water flows horizontally through the aquifer. Its unit is m^2/s and is represented by T.

The storage coefficient (storativity) or specific yield represents the volume of water that can be taken out from the storage. It can be defined as the volume of water released from an aquifer per unit change in head per unit cross-sectional area of the aquifer. It is represented by S. It is a non-dimensional quantity and is generally expressed in percentage. The storage coefficient refers to the confined part of the aquifer whereas specific yield refers to the unconfined part of the aquifer.

OBJECTIVE OF THE PRESENT STUDY

- To find out the soil parameters (T and S) by the pumping test on sands having different grain sizes arranged in homogenous formations.
- To check the effect of the position of observation well on the consistency of results

Unsteady Flow for the Unconfined Aquifer

The drawdown in an unconfined aquifer is small; the confined aquifer equation provides a good approximation. However, if the drawdown is significant, then the assumption that the water is released from the storage instantaneously is violated in case of unconfined aquifer. Pumping test data show that the water table is lowered and the gravity drainage of water from the unsaturated zone takes place at a variable rate which is called delayed yield.

Boulton (1963) developed a special type curve for analyzing pumping test data in case of unconfined aquifer using the concept of delayed yield. The curve for the delayed yield is shown in Figure 1.

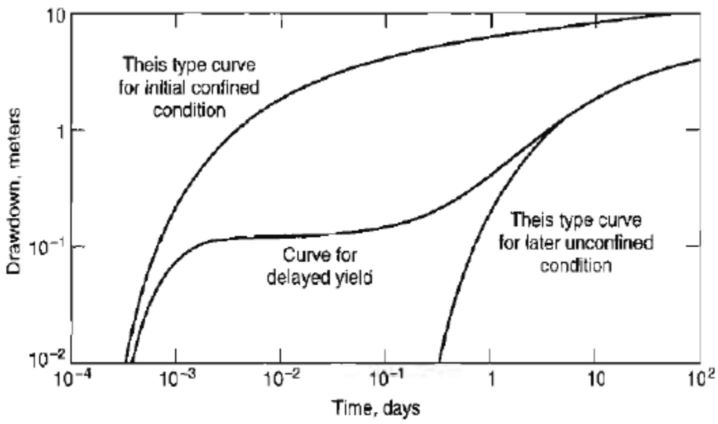

Figure 1: Type Curve of Drawdown versus Time Illustrating the Effect of Delayed Yield for Pumping Test in Unconfined Aquifer (Todd 2005)

Here the curve consists of three different segments. The first segment is measured in seconds to few minutes; water is released mainly from the storage by the compaction of aquifer and expulsion of entrapped air. Initially the system behaves as a confined aquifer so the storage coefficient will also be taken for the type curve as for the confined aquifer. Second segment shows the flattering of the slope caused by gravity drainage replenishment from the pore space above the cone of depression. The third segment occurs after several minutes to a few days and at this stage equilibrium is reached between gravity drainage and decrease of the water table. The pumping should be carried out for sufficiently long time so that the third segment of the curve can be obtained accurately. The storage coefficient obtained from this segment is equal to the specific yield and it is most reliable and hence important.

The equation presented by Neuman (1975) for the well in unconfined aquifer penetrating fully is given below which is used for present study.

$$s = \frac{Q}{4\Pi T} W(u_a, u_y, \eta)$$

$$u_a = \frac{r^2 S}{4Tt} \quad (applicable\ for\ early\ drawdown\ data)$$

$$u_y = \frac{r^2 S_y}{4Tt} \quad (applicable\ for\ later\ drawdown\ data)$$

$$\eta = \frac{r^2 k_z}{r^2 k_h}$$

EXPERIMENTAL SETUP AND PROCEDURE

The equipment used in the experiment is shown in figure 2 with arrows indicating different parts.

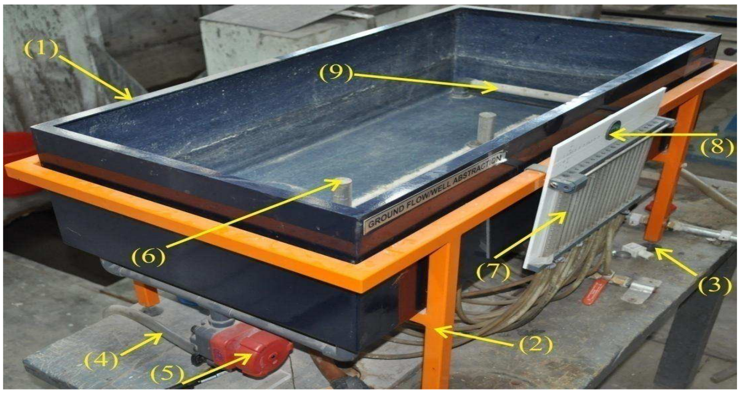

Figure 2: Schematic of the Instrument Showing Different Part

The equipment consists of

- Sand tank which is made from glass reinforced plastic.
- This sand tank is mounted on mild steel frame.
- For levelling the instrument there are four adjustable feet.
- Two water inlet ports are separately connected at each end of the tank.
- Each inlet port has a flow control valve to control the flow, which allows a fixed level in the tank to be determined.
- Two separate wells with controlling taps is connected at the base of the tank which allow the studies of abstraction.
- Nineteen taps are at the base of the tank which is connected to a multi tube manometer. This manometer arrangement is clipped at the side of the frame. The manometer is easily removable so that priming can be done. This can also be used to drain the sand tank fully. There is a sliding scale on the manometer which allows taking the measurement at any level within the tank.

The overall dimensions of the setup is as follows

Length - 1.115 m

Width - 0.585 m

Height – 0.530 m

PIEZOMETER POSITION IN CRUCIFORM ARRANGEMENT

Here is the top view which is showing the position of the piezometer position in the tank

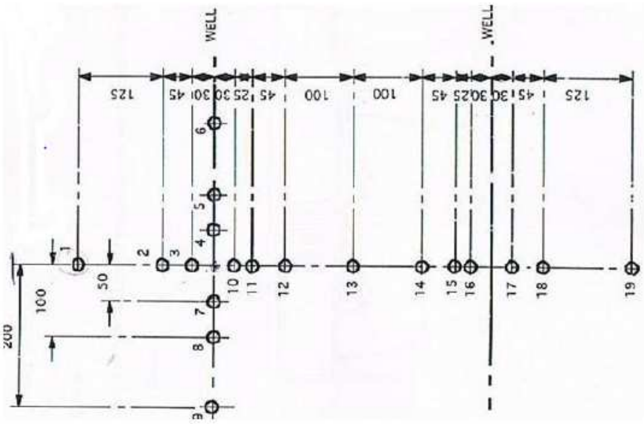

Figure 3: Piezometric Position, All Dimensions are in mm (Source Instruction Manual)

SAND PARTICLE SPECIFICATION

In order to study the water table drawdown and the well abstraction, the recommended sand size range between 0.6 mm to 2 mm. Also the sand used should be thoroughly washed to remove the silt and salt presents.

Methodology

- **Instrument setup**: By filling up the tank with the desired sample up to the height of well, bed is prepared. Bed is made saturated by controlling the water from the inlet valve.
- **Operation:** Pumping is carried out to get the drawdown. For the pumping, well is operated with the help of controlling taps for different discharge. The discharge should remain constant during the pumping. A manometer frame is provided at the side of tank which shows Piezometric level. As the pumping starts, an arrangement is made for taking the photographs of the manometer frame at an interval of one second.
- **Analysis:** From the photographs, readings for head at various time is noted down. From the head we can calculate drawdown by subtracting head from the initial level (level before start of pumping). Graph between drawdown versus time is plotted.

RESULTS AND DISCUSSIONS

Data Obtained for Fine Sand

The graphs for three different discharges are obtained. Here the graphs are plotted for the well number 13 and 12 which are at a radial distance (r) of 200 mm and 100 mm respectively from the pumping well.

Radius from the Pumping Well = 200 Mm

This section presents the plots and the calculations for the Piezometer located at a radial distance of 200 mm from the pumping well.

The three discharges are

- $Q1 = 1.72*10-5 m3/s$
- $Q2 = 1.67*10-5 m3/s$
- $Q3 = 1.64*10-5 m3/s$

Figure 4 shows graph obtained between time and drawdown for all three discharges.

From the figure we can see that drawdown is increasing with time. In the beginning rate of drawdown is slow but after few seconds it starts to increase at faster rate.

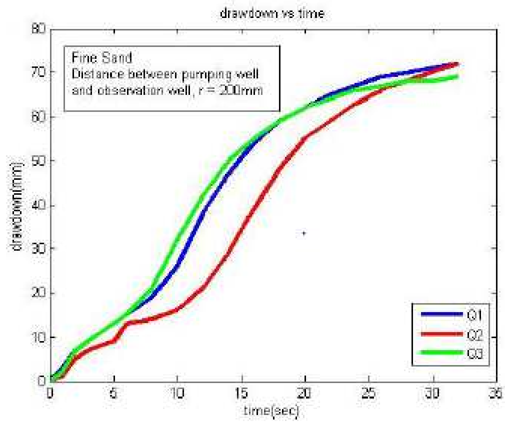

Figure 4: Drawdown V/S Time

Calculation for 1st Discharge, Q1= 1.72*10-5 M3/S

Figure 4 (a) shows matches of initial data plot of time and drawdown with type-a curve. Later data points fit with type-y curve as shown in Figure 4(b)

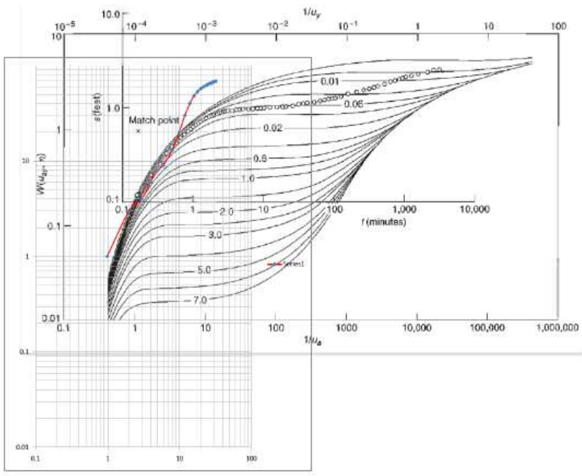

Figure 4(a): Time- Drawdown Curve, Fine Sand, R = 200 Mm (Initial Part Matching)

The match points recorded are-

- For type-a cure i. e. initial part [Figure 4(a)]

  η = 0.02

  w(ua) = 1

  1/ua = 1

  s= 21 mm

  t= 2.5 sec

  $T = 6.52 * 10^{-5} m^2/s$

  S= 0.0163

- For type-y curve i. e. later part [Figure 4(b)]

  w(uy) = 1

  1/uy = 1

  s= 28

  t= 15

  $T = 4.89 * 10^{-5} m^2/s$

  S= 0.0733

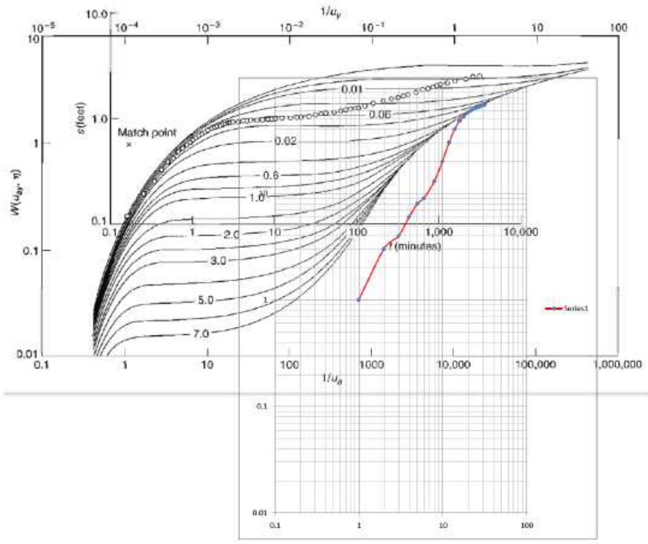

Figure 4(b): Time- Drawdown Curve, Fine Sand, r = 200 Mm (Later Part Matching)

Similar calculation is performed for other discharges. Values of specific storage and transmissivity for all the discharges are shown in Table 1.

Table 1: Values of S and T for R = 200 mm, Fine Sand

	Initial Part		Later Part	
	T (m^2/s)	S	T (m^2/s)	S_y
Q1= 1.72*10^{-5}	6.52*10^{-5}	0.016	4.89*10^{-5}	0.073
Q2= 1.64*10^{-5}	5.93*10^{-5}	0.015	5.22*10^{-5}	0.052
Q3= 1.67*10^{-5}	4.58*10^{-5}	0.018	4.28*10^{-5}	0.081

Radius from the Pumping Well = 100 mm

Figure 5 shows drawdown plotted against time**.**

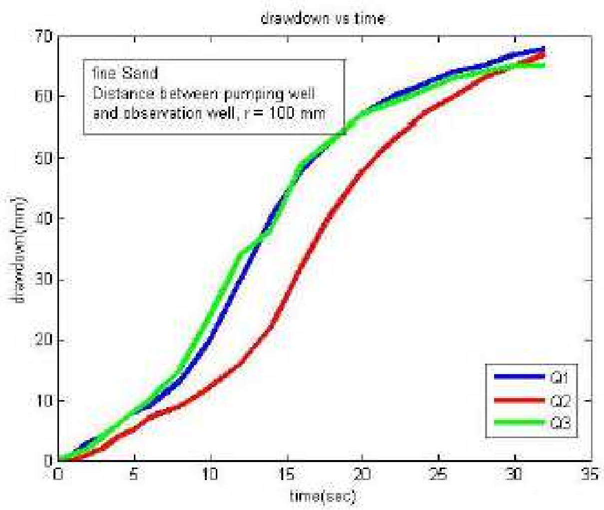

Figure 5: Drawdown v/s Time

Calculation for 1st Discharge, Q1= 1.72*10-5 M3/S

Figure 5 (a) shows matches of initial data plot of time and drawdown with type-a curve. Later data points fit with type-y curve as shown in figure 5 (b)

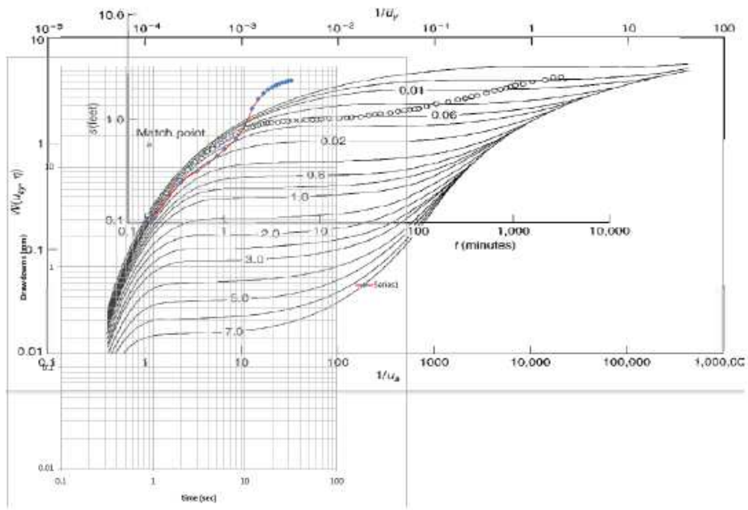

Figure 5(a): Time- Drawdown Curve, Fine Sand, R = 100 Mm (Initial Part Matching)

The match points recorded are-

- For type-a cure i. e. initial part [Figure 5(a)]

η = 0.02

w(ua) = 1

1/ua = 1

s= 18 mm

t= 0.8 sec $T = 7.60*10^{-5} m^2/s$

S= 0.02

- For type-y curve i. e. later part [Figure 5 (b)]

w(uy) = 1

1/uy = 1

s=39

t= 11 $T = 4.56*10^{-5} m^2/s$

S= 0.20

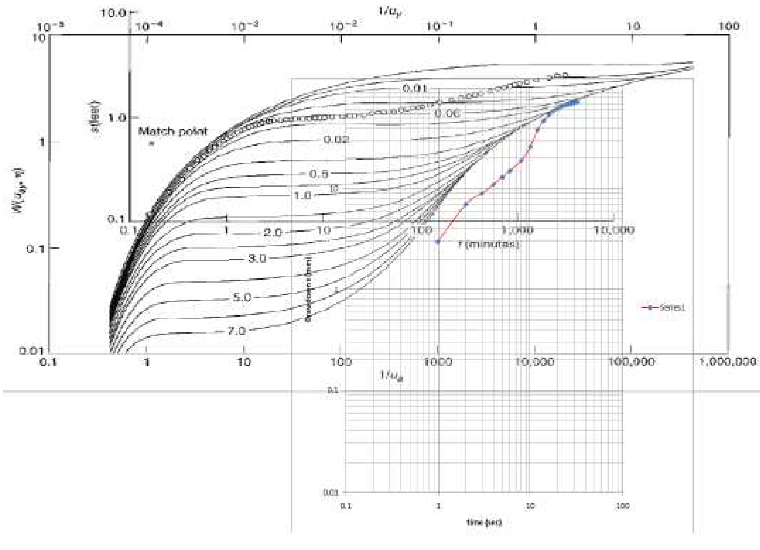

Figure 5(b): Time- Drawdown Curve, Fine Sand, r = 100 mm (Later Part Matching)

Similar calculation is done for other discharges at r = 100 mm.

Table 2: Values of S and T for r = 100 mm, Fine Sand

	Initial Part		Later Part	
	T (m^2/s)	**S**	**T (m^2/s)**	**S_y**
Q1= $1.72*10^{-5}$	$7.60*10^{-5}$	0.02	$4.56*10^{-5}$	0.20
Q2= $1.64*10^{-5}$	$4.21*10^{-5}$	0.03	$4.35*10^{-5}$	0.38
Q3= $1.67*10^{-5}$	$7.81*10^{-5}$	0.031	$3.32*10^{-5}$	0.39

Data Obtained for Coarse Sand

In case of coarse sand also graphs for three different discharges are obtained and they are plotted for the well number 13 and 12 which are at a radial distance of 200 mm and 100 mm respectively from the pumping well.

Radius from the Pumping Well = 200 mm

This section presents the graphs and the calculations for the Piezometer which is at a radial distance of 200 mm from the pumping well.

The three discharges are (m3/s)

Q1=1.35*10-5

Q2=1.63*10-5

Q3=1.87*10-5

Figure 6 shows the drawdown observed at different time.

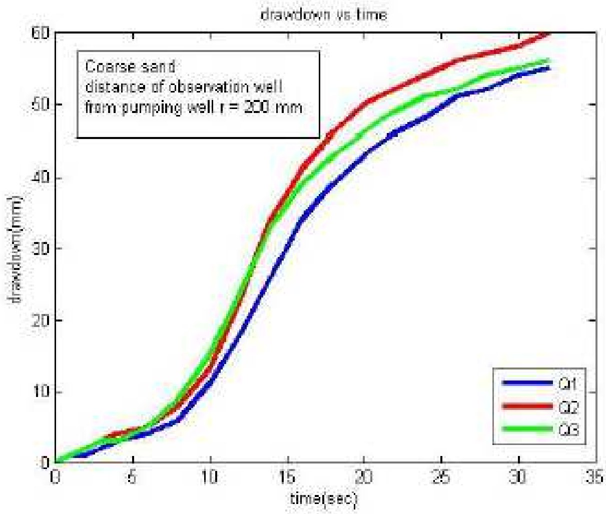

Figure 6: Time-Drawdown Curve

Calculation for 1st discharge, Q1=1.35*10-5 M3/S

Figure 6(a) shows matches of initial data plot of time and drawdown with type-a curve. Later data points fit with type-y curve as shown in Figure 6 (b)

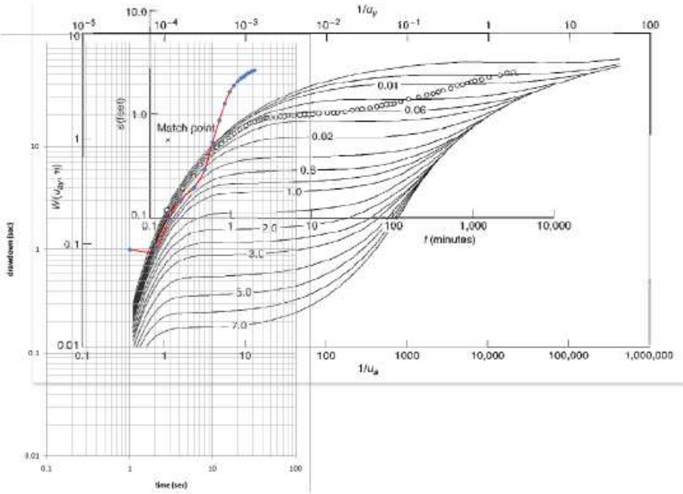

Figure 6(a): Time- Drawdown Curve, Coarse S and, r = 200 mm (Initial Part Matching)

The match points recorded are-

- For type-a cure i. e. initial part [Figure 6(a)]

  η = 0.31

  w(ua) = 1

  1/ua = 1

  s= 13 mm

  t= 2.7 sec

  T=8.26$*10^{-5}m^2/s$

  S= 0.022

- For type-y curve i. e. later part [Figure 6(b)]

  w(uy) = 1

  1/uy = 1

  s= 25

  t= 14

  T=4.297$*10^{-5}m^2/s$

  S= 0.0602

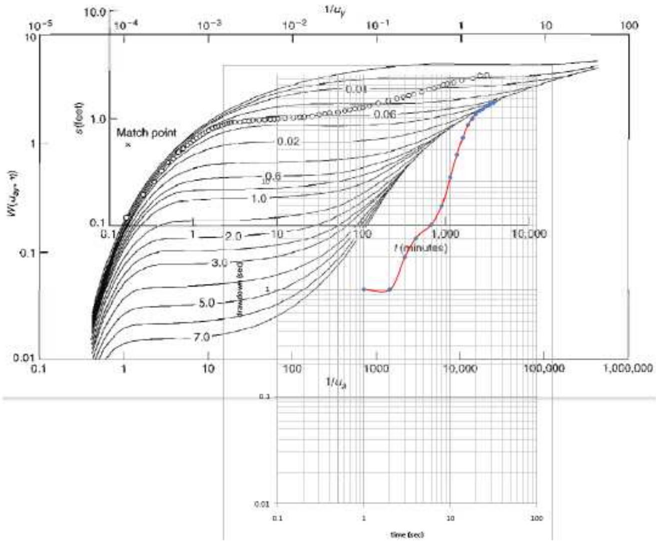

Figure 6(b): Time- Drawdown Curve, Coarse S and, r = 200 mm (Later Part Matching)

Similar calculation is done for other discharges too. Table-3 shows the value of S and T for all the three discharges.

Table 3: Values of S and T for r = 200 mm, Coarse Sand

	Initial Part		Later Part	
	T (m^2/s)	S	T (m^2/s)	s_y
Q1= $1.35*10^{-5}$	$8.26*10^{-5}$	0.022	$4.30*10^{-5}$	0.060
Q2= $1.63*10^{-5}$	$1.73*10^{-4}$	0.023	$4.80*10^{-5}$	0.086
Q3= $1.87*10^{-5}$	$1.49*10^{-4}$	0.025	$4.96*10^{-5}$	0.099

Radius from the Pumping Well = 100 mm

Figure 7 shows drawdown plotted against time for all the three discharges for the well located at r = 100mm

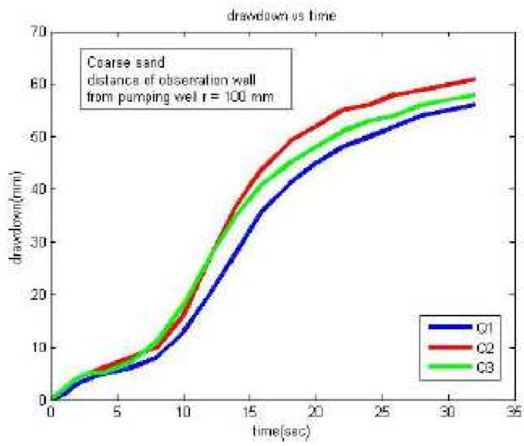

Figure 7: Time-Drawdown Curve when r= 100 mm (Coarse Grain Sand)

Calculation for 1st discharge, Q1=1.35*10-5 M3/S

Figure 7(a) shows matches of initial data plot of time and drawdown with type-a curve. Later data points fit with type-y curve as shown in figure 7(b)

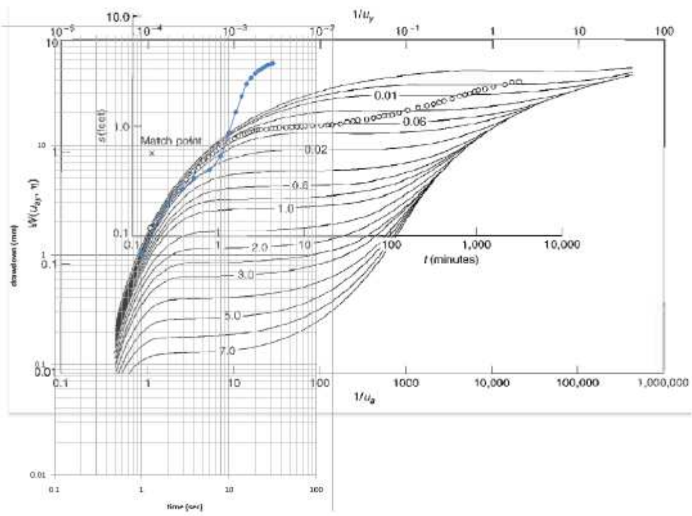

Figure 7 (a): Time- Drawdown Curve, Coarse S and, r = 100 mm (Initial Part Matching)

The match points recorded are-

- For type-a cure i. e. initial part [Figure 7(a)]

  η = 0.02

  w(ua) = 1

  1/ua = 1

  s= 9 mm

  t= 1.2 sec

  $T = 1.194 * 10^{-5} m^2/s$

  S= 0.057

- For type-y curve i. e. later part [Figure 7(b)]

  w(uy) = 1

  1/uy = 1

  s= 25

  t= 18

  $T = 4.297 * 10^{-5} m^2/s$

  S= 0.0309

Similar calculation is done for other discharges too at r =100 mm. Table-4 shows the value of s and t for all the three discharges.

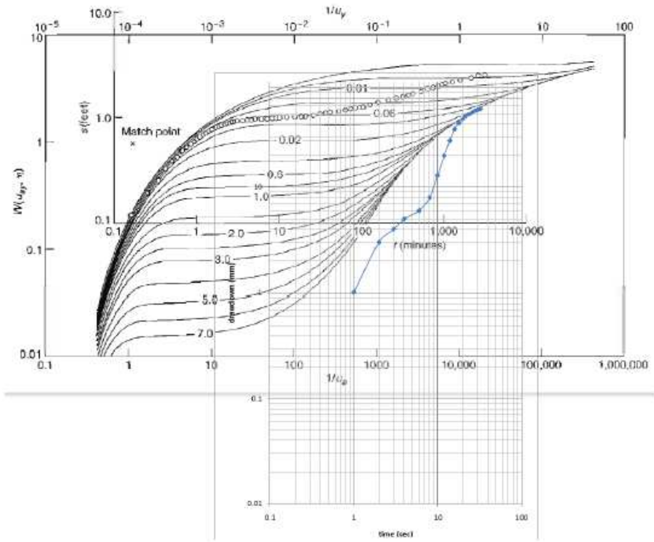

Figure 7(b): Time- Drawdown Curve, Coarse S and, r = 100 mm (Later Part Matching)

Table 4: Values of S and T for r = 100 mm, Coarse Sand

	Initial Part		Later Part	
	T (m^2/s)	S	T (m^2/s)	s_y
Q1= $1.35*10^{-5}$	$1.19*10^{-4}$	0.057	$4.30*10^{-5}$	0.309
Q2= $1.63*10^{-5}$	$1.64*10^{-4}$	0.046	$6.48*10^{-5}$	0.228
Q3= $1.87*10^{-5}$	$1.86*10^{-4}$	0.052	$7.44*10^{-5}$	0.217

SUMMARY AND CONCLUSIONS

The following observations may be drawn from the present study:

- The values of specific storage and specific yield calculated from the initial and later parts, respectively, of the drawdown curve showed that the estimates from the initial part are more consistent. One of the reasons for the inconsistency in the later part may be the short length of the experiment, implying that we do not get sufficient data points for the type curve matching. The other reason may be that initially the aquifer behaves as confined but later on it starts behaving as unconfined and, in general, confined conditions provide more satisfactory results as compare to the unconfined aquifers.

- Some of the results are subjected to the boundary effect since the drawdown cone extends to the apparatus boundary within a short time of the start of the pumping. Under confined conditions, it is relatively easier to incorporate the boundary effects but it is more difficult to do so for the later unconfined conditions. Efforts to estimate the aquifer parameters through theoretical consideration of the boundary effects were not successful, although acceptable accuracy was achieved in the analysis of the early time drawdown data.

- For the sand samples use d in the experiment, the values of S_y are in the range of 0.2 to 0.4 as obtained from the data at the observation well at a distance of 100 mm, which is in agreement with Nwankwor et al. (1992). The transmissivity values were predicated reasonably well.

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